Compliance Boundaries for LTE Base Station Antennas at 2600 MHz

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***Abstract*—Compliance boundaries and allowed output powers based on on the whole body averaged specific absorption rate (SAR) and the 10 g averaged SAR in both the limbs and the head and trunk and the root mean squared electrical field, are determined for three orientations regarding three base station antennas (BSAs) emitting at 2600 MHz. The ICNIRP basic restrictions and reference levels for both the general public and occupational exposure, are used to determine these compliance boundaries. FDTD simulations are carried out using the virtual family male and CAD models of the three antennas. The results for the different basic restrictions and reference levels are compared and we observed that the reference levels are not conservative when the antenna is only partially radiating. The simulation results show that the basic restriction on the 10g averaged SAR in the head and trunk of the body determines the compliance boundaries at lower antenna powers. Combined compliance distances, which ensure compliance with all reference levels and basic restrictions, have been determined for every frequency. The errors on the estimated allowed power are used for an uncertainty analysis for the compliance distances.**

I. Introduction

Both instructed radio frequency (RF) workers and ordinary people can approach base station antennas (BSAs). In order to protect them from possible RF induced health effects, compliance boundaries based on the ICNIRP basic restrictions (BR) on whole body averaged specific absorption rate (SAR), 10g localized SAR and electric field (reference levels (RL)) [1] are determined. Earlier studies have studied these quantities around several BSAs [2]–[5]. In other studies compliance boundaries have already been studied for GSM (900 MHz) [3], [6] and other frequencies [4], [5], [7], using generic BSAs or dipole arrays. The influence of a reflective environment has also been studied [2], [8]. Recently LTE (Long Term Evolution [9]) BSAs have been developped and are now in use. We have studied the compliance distances at 2600 MHz for three LTE BSAs placed in the vicinity of the heterogeneous virtual family male (VFM) [10]. The VFM is placed in front, at the back, and at the side of the BSAs at several separation distances. 3D electromagnetic (EM) finite-difference time-domain (FDTD) simulations are used to perform the computations.

II. Methods

A. LTE Base Station Antennas

Three LTE base station antennas emitting at 2600 MHz are modelled, based on real, multiple frequency BSAs. They consist of an array of patch antennas, with the upper part of the antenna emitting at 2600 MHz. The other half of the antenna is designed to operate at different frequencies, and will be considered as non-emitting in this study. Table I shows the characteristics of the BSAs.

B. Virtual Family Male

The VFM [10], selected to carry out the FDTD simulations, is a model based on magnetic resonance images (MRI) of a healthy volunteer. This adult model has a height of 1.80m, a weight of 72.2kg and consists of more than 80 different tissues. The dielectric properties of the body tissues have been taken from the Gabriel database [11]. The horizontal distance between the VFM and the BSA is measured between the centers of the bounding boxes of both the VFM and the BSA. A separation of 0 mm is defined as the distance where the outer boundaries of the two bounding boxes overlap. The center of the VFM is vertically aligned to the center of the whole BSA. The VFM is always facing the BSA and is placed in front of the BSA, at the side of the BSA or behind the BSA. The VFM is then translated along the respective direction from 0 to 5000 mm.

C. Simulations

FDTD simulations have been carried out using SEMCAD-X. The maximum grid step inside the VFM is chosen to be 2 mm to ensure accurate SAR results.

TABLE I
ANTENNA CHARACTERISTICS

	Antenna 1	Antenna 2	Antenna 3
Lenght [m]	1.4	2.2	2.8
Gain [dBi]	14.2	16.3	17.5
Hor. Beam width -3 dB [$^\circ$]	84	82	74
Vert. Beam width -3 dB [$^\circ$]	11.5	8.5	5.5
Polarization	Dual Linear $\pm$ 45 $^\circ$		
Number of radiating patch antennas	6	8	12

Uni-axial perfectly matched layers are applied at the edges of the simulation domain to avoid reflections back into the simulation domain. Two types of FDTD simulations have been carried out: simulations with only the antenna present and simulations where both the antenna and the phantom are present. In the first case, the root mean square electrical field E_{rms} surrounding the antenna is averaged over the volume where the bounding box (dimensions: 385 x 572 x 1836 mm^3) of the phantom would be. In the second case, the SAR values in the phantom are extracted, leading to values for the whole-body averaged SAR (SAR_{wb}) and the maximum of the 10g averaged SAR (SAR_{10g}) both in the limbs or in the trunk and head. As the output power (P_{out}) of the antenna is known and the phantom is translated at the front, side and back of the antenna, this leads to relationships $E_{rms}(P_{out}, d)$, $SAR_{wb}(P_{out}, d)$ and $SAR_{10g}(P_{out}, d)$ where d is distance, for every orientation.

D. Compliance boundaries and allowed powers

The RL for the electric fields and the BR on SAR_{wb} and SAR_{10g} defined by ICNIRP [1] are used to determine compliance boundaries for the BSAs. A compliance distance $d^{SAR_x}_{compl}(P)$ is defined as the distance from the antenna where for a certain power P, the SAR_x (x =wb or 10g) values equal the BRs. A similar compliance distance can also be defined using $E_{rms,volume}$ and the RL. The output power that causes the SAR values to equal the BRs or the E_{rms} values to equal the RL is called the allowed power $P^y_{compl}(d)$, where y = E_{rms} or SAR_x.

III. Results

A. Uncertainty analysis

There are numerical uncertainties associated to FDTD simulations. From [8], [12] the overall estimated expanded uncertainty (k = 2) with 95 % confidence interval is 59 % for SAR_{wb} and 64 % for SAR_{10g}. Since the allowed power is a scale factor that is determined using these SAR values, the errors on the allowed power will be the same as the uncertainty on the determined SAR values. Using the uncertainty margins on the allowed power, we can calculate error margins on the compliance boundaries. For a maximal output power of 120 W at 2600 MHZ these errors range from 60 % to 81 % for the SAR_{wb} and from 50 % to 95 % for the $SAR_{10g,trunk}$.

B. Compliance distances and allowed powers

Figure 1 shows the relationship between the allowed output power and the compliance distance. The figure shows the output power P of LTE antenna 1 that is required for SAR (E-field) values to reach the BR (RL) at a distance d. The compliance boundaries based on the BRs are given for both occupational (occ) exposure and the general public (genpub). For example: for an power of 17.3 dBW (53.7 W), $d^{E_{rms}}_{compl,front}$ = 1000 mm. The markers show simulation results and the curves show a cubic spline interpolation

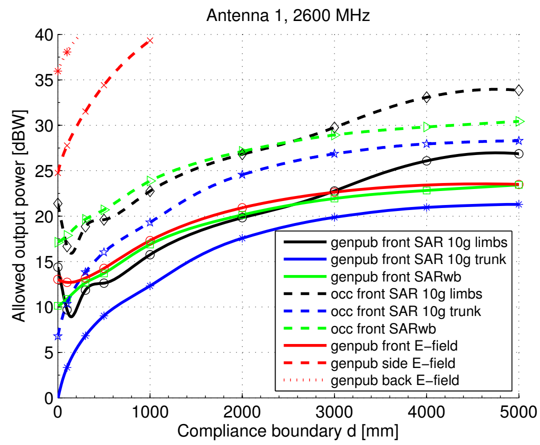

Fig. 1. Compliance distances for E_{rms} and SAR values for antenna 1

using those results. The powers that are necessary to reach the RL at the **side** and **back** of the antenna are also shown in figure 1. The compliance distance is larger in front of the antenna, as the antenna's main beam is in this direction. For the same power of 17.3 dBW the RL cannot be reached at the side and back of antenna 1. A power of 39.3 dBW (8.5 kW) will result in $d^{E_{rms}}_{compl,side} = 1000$ mm and $d^{E_{rms}}_{compl,back} = 190$ mm. Note that the RLs for the electric fields do not lead to a larger compliance distance, although RLs are intended to be more conservative than the BRs [1]. We attribute this to both the fact that the phantom is exposed locally and the quadratic relationship between incident power and electric fields. For antenna 1, the BR on the peak SAR_{10g} in the head and trunk ($SAR_{10g,trunk}$) causes the largest compliance boundaries (for distances < 5 m).

Fig. 2 shows the output power needed to obtain the BR for the general public (left axis) and occupational exposure (right axis) on SAR_{wb} for all three antennas. As shown in Fig. 2, the largest compliance distances based on SAR_{wb} are also found in the direction of the antenna's main beam. The values for the allowed powers in front of and at the

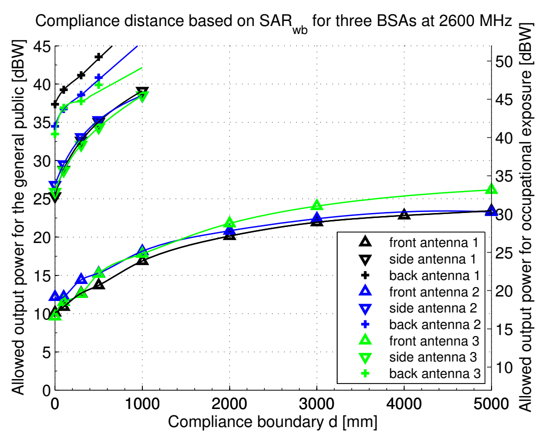

Fig. 2. Compliance distances for the three antennas, based on the SAR_{wb}.

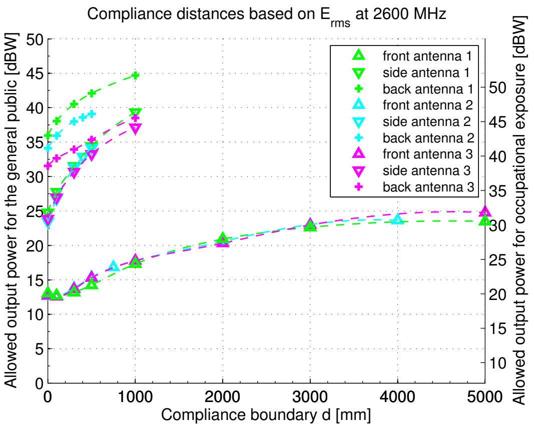

Fig. 3. Compliance distances for the three antennas, based on E_{rms}.

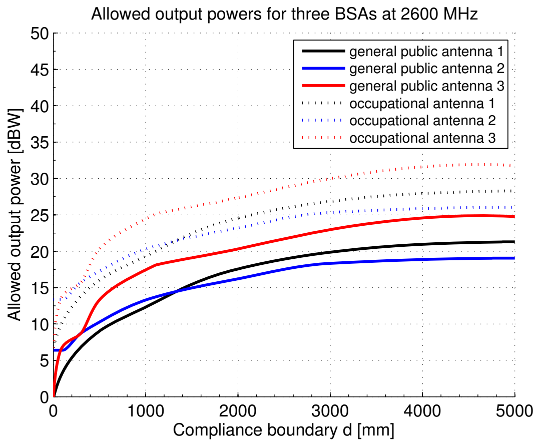

Fig. 5. Combined compliance distances for the three antennas.

side of the antennas do not deviate much for the different antennas, as the differences in allowed powers are < 3 dB. These are within the uncertainty margin (see section A) on the simulation results. Only at the back larger (> 3 dB) deviations between the antennas occur, as the antenna design is important in determining the exposure at the back of the antenna. Similar results are seen in Fig. 3 where the allowed powers and compliance distances are shown for occupational exposure (right axis) and the general public (left axis), based on E_{rms}. Volume averaging E_{rms} or mass averaging the SAR_{wb} over the (bounding box of the) phantom almost cancels out the differences in antenna design, length and number of radiating patch antennas (see Table I), showing that these presented results will be more generally applicable than just for the three studied antennas. When comparing the values shown in Figs. 2 and 3, one can conclude that the reference levels are indeed not always conservative. The results for occupational exposure and the general public can be shown in one figure since they will only differ by a factor of 5 for the BRs and RLs.

The allowed powers and compliance distances based on the SAR_{10g} are shown in Fig. 4. The curves show more deviation for the different antennas, as the position and value of the peak 10 g SAR will depend on the antenna length, design and position of the antenna's radiating parts. When comparing Figs. 2 to 4 one can see that at low powers ($P_{out} < 15$ dBW or 31.6 W) the compliance distance will be determined by the $SAR_{10g,trunk}$. As shown in Figs. 2 and 4, $SAR_{10g,trunk}$ does not always lead to larger compliance boundaries. For example for $P = 25$ dBW (316 W), the $d_{compl,front}^{SAR_{10g,trunk}} = 3060$ mm and $d_{compl,front}^{SAR_{wb}} = 3670$ mm for antenna 3. The allowed powers at the side and back of the antennas are not shown here in Fig. 4 because they are situated at unrealisticly high output powers. On average the allowed output powers at the side of the antennas will be 20 and 16 dB higher for $SAR_{10g,trunk}$ and $SAR_{10g,limbs}$ respectively. At the back of the antennas a power of 26 and 27 dB higher, for $SAR_{10g,trunk}$ and $SAR_{10g,limbs}$ respectively, will be allowed on average.

The actual compliance distance -referred to as the combined compliance distance- is defined by the curve that gives the largest distance at a constant power. As Fig.5 shows, these are determined by $SAR_{10g,trunk}$ at lower powers, but at higher powers other compliance distances can become dominant. When a perimeter around the antennas is determined, these allowed powers and compliance distances will have to be implemented.

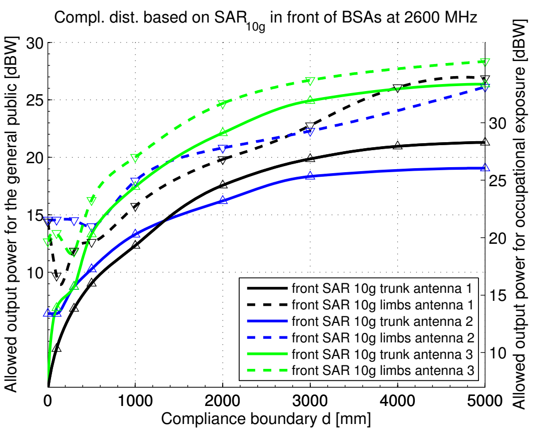

Fig. 4. Compliance distances for the three antennas, based on SAR_{10g}.

IV. Conclusions and Future Research

We succesfully determined compliance boundaries for three LTE base station antennas based on the ICNIRP basic restrictions and reference levels, using FDTD simulations with models for these base station antennas and the virtual family male. Compliance boundaries are determined based on the SAR_{wb}, $SAR_{10g,trunk}$, $SAR_{10g,limbs}$ and E_{rms}. These are compared for the three antennas at three orientations. The BR on the $SAR_{10g,trunk}$ causes the largest compliance boundaries at lower powers. Compliance boundaries based on SAR_{10g} show more dependence on the used antenna, while those based on SAR_{wb} and E_{rms} are similar for the different studied antennas and can be generaly applied for similar base station antennas. Combined

compliance distances have been determined for the three antennas.
The other frequencies emitted by the antennas and other pahntoms will also be studied. Cumulative compliance boundaries, where exposure from multiple frequencies is present, can than be determined. We are also looking into using surrogate modelling as a tool to determine allowed powers in a 2D plane or 3D environment surrounding the antennas.

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